

ECSE-2210 Microelectronics Technology
Class Activity 3 – Solution

- 1) Intrinsic Si has $1 \times 10^{10} \text{ cm}^{-3}$ electrons in its conduction band at 300 K. What will be the number of holes in the valence band?

In intrinsic Si, the number of electrons is equal to the number of holes because a hole is created in the valence band whenever an electron “jumps” from the valence band into the conduction band. The number of electrons in the conduction band is called “free electron concentration”, n , and the number of holes in the valence band is called “free hole concentration”, p . In an intrinsic semiconductor, $n = p = n_i$ at any given temperature. The values of n_i depends on the bandgap as well as on the temperature.

- 2) Consider three intrinsic semiconductors: Ge, Si and GaAs.
- a. Which one has the largest number of electron-hole pairs at room temperature? Explain briefly.

Ge. The lower the band gap, the less energy is required to generate electron – hole pairs (EHP). Note the values of intrinsic carrier concentration, n_i for different semiconductors n_i is smallest for GaAs and largest for Ge.

- b. Which one has the highest resistivity at 300K? Explain.

GaAs has the lowest number of electron-hole pairs since it has the largest bandgap. It takes more energy to create EHP in GaAs compared to Ge. The resistivity depends on the number of EHP. GaAs has the highest resistivity or the lowest conductivity. Ge has the lowest resistivity at 300K.

- c. Suppose each one is doped with a donor concentration of 10^{16} cm^{-3} . The donor binding energy (or ionization energy) is 0.06 eV. Make a guess of the electron concentration in each sample at 300 K? Are they the same or different? Explain.

Each donor has one extra electron to give to the lattice (or to the conduction band). Since the energy needed to remove an electron from the donor is so small (0.06eV) at room temperature, we can assume that all the donors are ionized. So, in general, all samples will have the same number of electrons at 300 K. Of course, we will have some extra electrons that jumped from the valence band to the conduction band, but their number is several orders of magnitude smaller than the 10^{16} cm^{-3} electrons from the donors. So, the intrinsic electron-hole pairs do not matter since their concentration is small compared to 10^{16} cm^{-3} . Note that the number of electrons in the material is determined by the donor concentration and is *independent* of whether the material is GaAs or Si or Ge.

- d. If each one of the doped semiconductors is heated slowly above 300 K, which one will convert to “intrinsic” first? Which one will convert to intrinsic last? (For all practical purposes, “intrinsic” means the electron and hole concentrations are almost equal).

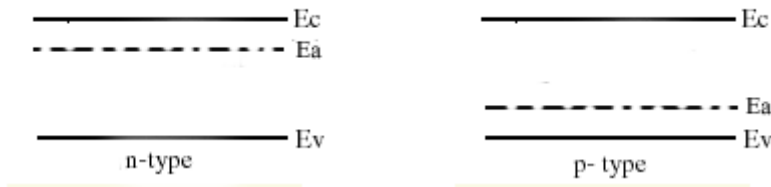
Ge becomes intrinsic first. It is easier to generate EHP in Ge since its band gap is small. As the temperature is raised, the EHP pairs generated (i.e., the number of electrons jumping from the valence band to the conduction band) will keep increasing. The number of EHP will increase at a faster rate for Ge than for GaAs. At a certain temperature, the EHPs generated by this process will exceed the number of electrons (10^{16} cm^{-3}) from the donors. Then the effect of donors can be neglected, and the semiconductor is practically intrinsic (i.e, $n = p$).

- 3) Calculate the ionization energy of a donor atom in Si. Assume $\epsilon_s/\epsilon_0 = K_s = 11.8$ and $m_n^*/m_0 = 1.18$ for Si. You can start from the fact that the electron binding energy within the hydrogen atom is 13.6 eV as calculated in class activity 2.

$$E_B = \frac{m_n^*}{m_0} \frac{1}{K_s^2} E_{H(n=1)} = -0.1 \text{ eV}$$

- 4) Mention two n-type dopants and two p-type dopants in Si. Draw the band diagram of an n-type Si sample. Draw the band diagram of a p-type Si sample.

P, As, Sb are n-type dopants because they can donate an electron. (One extra electron compared to Si).



B, Ga, Al are p-type dopants because they lack one electron less than Si. They take an electron from the lattice creating a “hole”.

- 5) Electrons in a filled band cannot participate in current flow. Explain why.

In a filled band, for every electron that is moving in one direction, there is another one moving in the opposite direction. So the net current flow is zero. There should be an empty state in location B if an electron in location A has to move to B. The only way this can be accomplished is if the electron from location B moves to location A. This means the net charge flow is zero.